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COSMIC AND SOLAR NOISE

by

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INTRODUCTION

Each applicable extension in physical thought and appropriate new experimental technique has promptly been taken by the astronomer to study the characteristics of the sun and the radiation from outer space. Since the available experimental tools were developed chiefly in the fields of heat and physical optics, a great deal has been learned from analysis of solar and cosmic radiation in those frequency regions. Developments in electronics have only very recently made it possible to detect such radiation at the low frequencies, i.e., in the so-called radio spectrum of microwaves and below. This type of radiation is at extremely low intensity level and since it has a, more or less, continuous spectrum, it takes the form of radio noise.

This work has been greatly advanced by the radar equipments developed during World War II. Antenna arrays of all types, covering the longest radio waves to microwaves, are essential. The ability of antenna designers to create narrow beam antennas has made it possible to give increasingly sharp definition to the location of the sources of such radiation. In many cases it has limited the number of possible explanations for the generation of this radio noise and has caused scientists to discard several theories which previously had been considered plausible.

IMPORTANCE OF RESEARCH

Knowledge of the upper atmosphere has become increasingly important both from the military point of view and from the

viewpoint of radio transmission and astronomical knowledge, Since the sun is responsible for ionization of the various layers in the upper atmosphere, better prediction of optimum frequency for any period will be available from studies of solar noise.

Astronomers will have new data for probing into the chemical composition and turbulence on the sun and on galactic bodies. With the cooperation of developmental scientists a new navigational system operating through cloud formations but utilizing celestial navigational techniques would be initiated.

However, much of the widespread attention currently given this phenomenon stems from the integrating trend in physical thought. Analysis of the characteristics of solar and cosmic noise is a possible means of tying together facts concerning electromagnetic radiation in other frequency regions and nuclear theory. It may produce reasonable explanations to help us understand, for example, the ionization in our own atmosphere and the origin of cosmic rays. Theoretical proofs and laboratory data will supplement and help to correlate experimental measurements on solar noise bursts and sunspots. Scientists in England, Germany, Russia, Australia, Canada, India and the United States are concerning themselves with the collection and analysis of experimentally verified facts, suggestions as to integration with nuclear theory and experiments to simulate the generation of noise.

HISTORY

Karl Jansky(13) was the first to notice that a directional source of noise generation was affecting his radio propagation measurements. Through the use of an antenna variable only in azimuth he was able to locate the sources within the Milky Way. He picked up this radiation at noon with a rather wide beam antenna. He was unable to detect solar noise. Although Jansky first attributed the signal received to radiation from the sun in the radio frequency region, he later corrected himself. The extremely low intensity level of solar noise at quiet periods was not capable of being detected above receiver noise by his equipment. Later investigators used the techniques of allowing the antenna system to remain fixed (if the equipment was large and bulky) and noting the bell-shaped curve that resulted when the antenna's acceptance beam angle hit the source of radiation and of varying the azimuth and elevation of the antenna to find the disturbance source.

Further investigations revealed comparatively high intensity solar noise, predominantly in the 10 to 500 megacycle range. The gamut of radio frequencies was covered by experiments from microwaves to 10 megacycles. Recent investigations in the field of cosmic rays and solar noise have been concerned with radiation in the range 25 to 1000 cycles per second.(15) The data reveals strong intensities as high as one volt per meter in this region

Utilizing more and more sensitive equipment, standardizing on calibration techniques and further narrowing the acceptance angle of the antennas provided new and more accurate data. Intensity could be recorded as a function of time and the sun "homed" upon by antennas variable in azimuth and elevation. The same "tracking" methods were used to locate several sources of cosmic noise.

MEASUREMENTS AND MEASUREMENT TECHNIQUES

Solar radiation is extremely difficult to measure and to record in its normal "quiet sun" phases. In comparison to radiation from man made sources, solar noise is extremely weak. Cornell University in recent experiments* loses track of its objective when small aircraft come within seven miles of the antennas. The sources of energy whether from the sun or from the cosmos are extremely small. At times of high radiation from the sun, the sun spots are the apparent noise generators and their diameter is of minor magnitude.

Galactic noise obscures antennas of low directivity used in solar noise measurements so that huge antennas and many element beams are necessary for research in this field.

The development of radar techniques and actual equipment aided data taking. German Wurzburg equipment, British Yagi antennas, parabolic reflectors and similar equipments are being used to collect energy from the sun and the stars.

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* Personal Communications.

High gain low noise receivers are aiding in the development of good measurement techniques.

The radiant energy measurements are taken of the flux. Since the bandwidth of the receivers varies for each worker in the field it is the flux per megacycle bandwidth that must be specified. Radiant flux is the time rate of flow of electromagnetic energy. However, it is the steradiancy or the radiant flux per unit solid angle per square centimeter of the source in which we are interested(10).

In measurements of the radiant flux of non-blackbodies in optical work, the results are often converted back into temperatures as if the flux emanated from a blackbody. A blackbody heated to a specific temperature emits in a finite bandwidth a finite amount of energy. The converse of this would be to take a measured amount of energy and convert it back into a specific blackbody temperature. This standardizes on measurement techniques and measurements. Use of the term "blackbody temperature" also serves to tie together electromagnetic radiation in the fields of heat, light and radio frequency energy.

As a standard for radiation a body which has a reflectivity equal to zero and an absorbtivity equal to one is defined as a blackbody. The sum of reflectivity and absorbtivity is equal to one. Such a body radiates an amount of energy that depends on the temperature alone. The energy distribution according to frequency or wavelength is governed

by two laws:

1. The Stefan Boltzmann law gives the total radiant flux from a unit area of a blackbody as a function of temperature:

$$W = \sigma T^4$$

W is total radiant flux in ergs per second per square centimeter.

σ is the Stefan-Boltzmann constant equal to 5.709 X 10^{-5}.

T is temperature in degrees Kelvin.

It is interesting to note that radiation exerts a pressure when it falls on a surface acting very much like a gas when confined within a cylinder. The similarity of actions when radiation is confined within a perfectly reflecting cylinder and when gas is confined within a similar cylinder lead Boltzmann to his conclusions about radiant flux from an object varying with the fourth power of the temperature. The basic similarities will be taken up later when the gas surrounding the sun is used as the basis for explaining the steady component of solar noise.

2. Planck's radiation law shows how the radiant flux is distributed throughout the spectrum:

$$J_\lambda = \frac{A\, C_1\, \lambda^{-5}}{e^{\frac{C_2}{\lambda T}} - 1}$$

A is area in cm^2

J is spectral radiant intensity in watt/steradian/cm^2

T is temperature in degrees Kelvin.

C_1 (the first radiation constant)

C_2 (the second radiation constant)

Therefore, it is possible to take any known measurement of radiant intensity and refer to the source of this energy as being equivalent to a blackbody of a definite temperature.

Through measurements such as that of the solar constant (where the solar constant is the amount of the sun's radiation received on an unit area in unit time, the receiving area being perpendicular to the sun's rays and at a distance equal to the mean radius of the earth's orbit)(19) the equivalent blackbody temperature of the sun has been calculated to be 6800 degrees Kelvin.

NOISE

In receiver circuits there are four basic types of noise which affect measurement techniques (11):

1. Tube noise.
    a. Shot effect or discrete particles generating noise.
    b. Flicker effect due to cathode irregularities.
    c. Contact noise.
    d. Dirt noises.

2. Thermal noise of input resistance: The small internal loop currents caused by the thermal motion of the conduction electrons in a resistor cause noise which limits the minimum detectable signal of an amplifier to a value which is independent of the gain of the electronic system.

$e_b^2 = 4KTBR$

R input resistance

K Boltzmann's constant

e RMS volts

T Temperature in degrees Kelvin

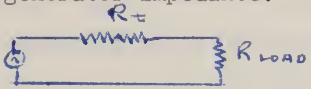
B Bandwidth in cycles per second.

3. The real or resistive part of the antenna circuit impedance.

4. Absorbed antenna noise. The absorbed antenna noise is partially due to ohmic resistance and partially to noise absorbed from space. This will include atmospherics as well as the radiation resistance noise.

All of these various types of noise can be lumped together into an equivalent circuit which has a noise generator and an generator impedance.

$e = \sqrt{4KTBR}$



R_t is now the total impedance of all four noise components. We now have a noise source and a network. The equivalent Johnson noise, as it is called, is a thermal effect and can be seen to be a function of bandwidth. It is not a function of frequency. For use of electronic work in solar measurements, it is necessary to bridge the gap between blackbody radiation and Johnson noise effects.

The problem might be set up artificially in the laboratory as follows (6): An antenna is placed inside of a blackbody. It is matched by a coaxial line which is loaded by a pure resistance. The terminating resistance is equivalent to the characteristic impedance of the line. If the antenna and the blackbody are at the same temperature as the resistor then there will be no transfer of energy due to thermodynamic laws. The antenna can then be referred to as having a certain temperature. It can also be shown (11) that no power transfer takes place between two resistors at the same temperature.

Planck's law states that spectral radiant intensity is a function of frequency. However, Johnson noise is frequency independent since it is strictly a function of bandwidth, temperature and resistance. It is necessary to reconcile these two laws for the region of wavelengths longer than the infrared. At these wave lengths Planck's law reduces to Rayleigh Jeans's

$$J_\lambda = AC\lambda^{-5} \left(\frac{\lambda T}{c_2} \cdot \right)$$

A is area in cm^2

J is spectral radiant intensity in watt/steradian/cm

T is temperature in degrees Kelvin

This law is accurate to within one percent when the product if λT is greater than 77 cm degrees (19).

Since radiation is then proportional to λ^{-2} and the average absorption cross section of an antenna is proportional to wavelength squared at higher radio frequencies, we have a neutralizing effect. The two factors $\lambda^{-2}, \lambda^{2}$ cancel one another and the total power is frequency independent.

Calibration of equipment for absolute sensitivity values utilized the principle of radiating a known amount of thermal or Johnson noise. Two sources of energy are used. The basis of calibration is a resistor heated to a known measured temperature. The heated resistor is then placed at the input terminals normally attached to the antenna. A source of calibration voltage is then available which can be controlled to stay within the range of input voltages from the normal antenna input. This calibration technique is automatic with a meter switching alternately from resistor input to antenna input. The principle is known as the radiometer principle and makes use of the equation $e^{2} = 4kTBR$

The received energy is, in effect, modulated by a differential in noise. Thus, the equivalence of thermal noise and blackbody radiation is used as a calibration technique. Absolute values of intensity are readily available. After the signal is amplified it is detected (5). The resulting D.C. voltage is used to drive a recording milliameter of the Esterline Angus type in most cases.

NOISE FIGURE AND THE QUIET SUN.

For a network such as a receiver the power gain available at the output equals $\frac{S_{out}}{S_{in}}$

The noise power generated by an ideal network which contributes no noise of its own $N_g = kTB$.

In order to be able to get the order of magnitude necessary for solar and cosmic noise in certain bands to override receiver noise, a definition of noise figure of a network should be undertaken.

$$F = \frac{\text{available input signal power/ideal available input noise power}}{\text{available output signal power/available output noise power}}$$

$$= \frac{N}{GKTS} = \frac{\text{actual output noise power}}{\text{noise power of ideal network having same gain and bandwidth.}}$$

The ideal receiver to pick up the signal would have a noise figure of 1. This would simply mean that the noise power out would be equal to the theoretical noise of the network. The contribution of the actual receiver to the total noise is then F-1.

Power absorbed by the receiver = $(F-1)kTB$

The temperature being considered is not the ambient temperature. Noise figures of receivers being used in the field in practice varies from 3 to 8 in the 300 megacycle region and 10 to 15 for microwave equipment (1).

If we take a mean value of $F = 10$ the ratio of optical sun (6800 degrees Kelvin) noise to receiver noise

$$\frac{p}{p_r} = 2 \times 10^{-5} \left(\begin{array}{l}\text{Gain of receiving antenna over}\\ \text{half wave dipole}\end{array}\right)$$

It is apparent that high gain antennas are needed to increase this ratio so that noise from the sun can be seen above ordinary receiver noise. In the case where an antenna has a gain of five, the noise from a blackbody of 6800 degrees K would only be 1/10,000 of the noise from the receiver itself.

THE QUIET SUN

It should be pointed out that at low radio frequencies (below the microwave region) even the "Quiet Sun", the sun without any unusual turbulence occurring on or near it, emits radio frequency radiation many times the calculated radiation from a body of 6800 degrees Kelvin. Quiet sun measurements are usually at least more than 100 times the value of expected blackbody temperature at long wavelengths. Due to theoretical requirements and measurements such as in the optical region, the sun is ruled out as a thermal source of 1,000,000°, the necessary blackbody temperature.

Another possible source of radiation is the corona. This is essentially a gaseous sphere with a radius greater than that of the sun. This outer envelope is of very great height and small density (20). Spectrographic measurements in the visible and ultraviolet frequency range indicate that the temperature of the solar corona is of the order of 1,000,000 degrees.

Figure 1 outlines the experiments and measurements made for quiet sun intensities.

Measurements of quiet sun radiation are in agreement in the longer wavelength area. The number of experiments performed is rather inadequate. Difficulties of extremely low amplitudes are probably the main reason for this. The range of amplitudes is the radio frequency band is from 50 times blackbody radiation at 200 megacycles to 300 times blackbody radiation at 160 megacycles. Southworth's microwave experiments which yielded 6800° K were in slight disagreement with Dicke and Beringer who reported 10,000° K at 1.2 cm. The latter used a more advanced technique for measurements and calibration, the radiometer principle.

SUNSPOT ACTIVITY

In order to integrate the information available into a coherent body, it will be necessary to correlate theory with the phenomena occurring at the same time as solar bursts. The nature and magnitude of these other disturbances or deviations from the norm plus the time sequential of events will point to a reasonable explanation of solar noise.

It is necessary to take into account cosmic ray intensities, magnetic field disturbances, ionospheric propagational factors, and solar noise measurements to get a unified theoretical explanation.

The entire mechanism of solar noise bursts seems to start with sunspot activity. It is surprising to see how many factors depend on this seemingly irregular phenomenon.

In 1942 Appleton and Hay (1) sought to ascertain the frequencies which were enhanced a maximum amount by solar flares. Measurements on frequencies ranging from 20 megacycles to 3,000 megacycles were made by cooperating groups in England. The peak enhancement over blackbody radiation was reached at 64 megacycles (See Figure 2). Peaks of up to 1,000,000 times blackbody radiation were recorded during the solar noise storm. The noise increased steadily from February 23, 1942, to February 28, 1942. It was negligible on March 1st. On the 28th of February solar flares were seen. Radio fadeout occurred on the same day from 1200 to 2000. A magnetic storm followed at 0727, 1 March.

At the same time as noise measurements were being taken cosmic ray intensity data recordings were made (9). A very narrow tunnel allowing for increased radiation opened up for a short time late on February 27 or early on February 28. This increase in intensity died down late on February 28th and opened up again for a brief time on March 1st. There was an increase of cosmic radiation on February 28th and again possibly a smaller one on March 1st.

A second series of correlated data was taken at Manchester (7) at the time of the large increase in solar noise and geomagnetic disturbance of July 25, 1946. Amplitudes of 13 percent above normal hourly rates made the disturbance unusual.

The magnetic disturbance ceased by 1000, July 27, 1946. At this time the cosmic ray intensity was 8 percent below normal. A very slow recovery as usual resulted in more than a week elapsing before the pre-storm level was regained. The storms have occurred from 17 hours (in 1942) to 25 hours (in 1946) before the magnetic disturbance started.

The overall sequence then appears as follows:

1. Sunspot activity.
2. Noise increasing slowly.
3. Solar flares appear visually.
4. Radio fadeout.
5. Cosmic ray intensity increase.
6. Magnetic storm.

The bursts of radio frequency energy have a frequency time relationship. In observations on the relative times of arrival of bursts on 200, 75, and 60 megacycles it was found by Payne Scott (16) and others that while the small bursts show no correlation, the larger bursts have a recognized time sequence (Figure 4). The sequence was 200 mc, 75 mc, and 60 mc. The time between 200 mc and 75 mc is of the order of two seconds. A similar time difference occurs between 75 mc and 60 mc. Exceptionally large outbursts have been recorded with two minutes delay between adjacent channels.

Closely associated with the periodic variations of the spots are similar periodicities of the faculae, the bright

streaks and patches on the sun's surface and limb (20). The number and distribution of the solar prominances and the form and extent of the corona show changes with the sunspot period.

Enhanced solar noise shows circularly polarized characteristics. During one set of measurements at 10.7 cm the polarized component changed from day to day (5). From June 23, 1947, to July 2, 1947, radiation changed from a predominantly left-handed to a predominantly right-handed polarization and back again. Very little energy from the sun at this frequency was linearly polarized. The reversal of the direction occurs when the sunspot crosses the meridian.

According to the law of sunspot polarity all bipolar spot groups in the northern hemisphere of the sun were polarized in the sense that the leading spot exhibited a south seeking pole while the following spot had a north seeking pole. The reverse arrangement prevailed in the southern hemisphere. However, this process is reversed with each 11 year cycle.

Ryle and Vonberg after corroborating early discoveries of circular polarizations (22) advance the theory that the characteristic polarizations are imposed on radio waves in their transmission through an ionized medium under the influence of a magnetic field. One explanation for this is that it is due to either the differential absorption of the oppositely polarized magnet ionic components or the suppression of one component by electron limitation.

Most of the experiments in solar noise have contributed vital bits of information which as yet is uncorrelated. Solar noise is not at its maximum when large sunspots are centrally located on the solar disk. Bursts of energy have a short term variability, changing by a factor of 100 within a few seconds. The basic character of this noise is similar to "hissing".

Enhancements over blackbody radiation during sunspot activity varied from 2 x 10^3 at 200 mc to 10^8 at 75 mc. Since two sets of experiments reached the conclusion that 65 - 75 mc was the point of maximum enhancement this fact seems conclusive.

COSMIC NOISE

The first radio frequency radiator discovered was the source located in the area of Sagittarius. The intensity of radiation was much heavier than the sun's radiation as Karl Jansky found out in his first measurements. Later measurements were taken mostly in the 20 to 500 mc range. The same type of apparatus can be used as is used in solar measurements.

One primary source of energy comes from the direction of the constellation Sagittarius, a group of magnitude 2.9. The noise from this direction is constant in intensity both as a function of time and as a function of frequency. The directivity indicates a source 11° in width. Measurements at various frequencies agree within a factor of 10 (Figure 5).

A less intensive but more interesting noise generator is Cygnus. The radiation has been narrowed to a source 2° in

diameter. Cygnus displays a temporal variation in intensity. The average variation was 15 percent of mean power received. The variations in power per unit solid angle correspond to more than five times mean power per unit solid angle for the whole beam. The fluctuations recorded are ample proof that widely distributed interstellar matter is not the origin of cosmic noise. At 175 mc interferometer measurements were taken to discover the polarization from Cygnus (2). The polarization is random rather than circularly polarized.

The general level of absolute intensity is 10 x 10^{-22} watts/cm^2/circ deg/mc of bandwidth for the main source of radiation, i.e., that of Sagittarius. The constancy of this source and the agreement of observers on the value obtained had led to the suggestions that a new means would be available of measuring the amount of attenuation which any particular solar burst would produce. The ratio of the intensity from Sagittarius when the sun was relatively clear of sunspots to the intensity of Sagittarius when a burst arrived would yield interesting results on the ionosphere as an attenuator. With this information available plus the band rejection characteristics of the ionosphere (to be described later) an equivalent network could well represent the effect of the ionosphere on radiation at all wavelengths.

ORIGIN OF SOLAR RADIATION

Some of the same characteristics are displayed by both solar and cosmic noise. The burst period of Cygnus can be

compared to the solar noise enhancement during sunspot cycles. The steady source of Sagittarius might be compared to the "quiet sun". It seems reasonable to believe that a single clear theory could account for both phenomena.

Another reason for associating the two noise sources is that rapidly rotating stars of early type have extended and turbulent atmospheres(12). These stars may possess phenomena on a grander scale than does the sun (magnetic phenomena have been observed in one star by the Mount Wilson Observatory).

Solar temperatures of several million degrees would be necessary to account for radiation during the upswings in solar noise reception. Optical measurements plus measurements in the microwave regions indicate a temperature in the neighborhood of 6000k to 6800k. While the corona maintains a temperature of 1,000,000° therefore accounting for the quiet sun measurements of many times blackbody radiation, it is necessary to find another source for the enhancement over quiet sun energies.

Nuclear physics seems to supply the most reasonable answer to this problem. One of Bohr's fundamental postulates was that an electron can move by a quantum jump from one stationary state to another, radiating a quantum of radiation in the transition. The difference in energy between the two states or levels is the amount radiated. This difference: $E = E_2 - E_1$ is equal to $h\nu$ where ν is the frequency of the radiated energy and h is Planck's constant. This set of

closely spaced energy level is basically due to nuclear spin. The ordinary levels of atoms usually bring transitions of such a nature that the frequency omitted is in the visual range or at the most down to microwave frequencies. However, magnetic fields will increase the number of levels or possible transitions and will act to produce some transitions which will be more closely spaced. A more closely spaced set will yield radio frequency radiation. By a process of excitation by a strong magnetic field of the energy levels of the nuclei of atoms and molecules, radio frequency energy has been absorbed (17) in laboratory experiments. Frequencies in the meter and microwave ranges have been explored. While no experiments have as yet generated energy in this region through molecular beam resonance techniques, the cause is due to the fact that the energy involved in emission would be extremely small unless a huge volume of the element is used.

Normal sodium atoms in one state can be expected to emit waves with a wavelength of 17.15 cm but such transitions are rare. We can expect one in 10^5 years. But when atoms are placed in a strong magnetic field and an additional small rapidly varying field is impressed at right angles to the fixed field we find energy absorbed when the period of the radio frequency field is comparable to:

$$\text{Period} = \frac{\text{Plank's constant}}{\text{energy}}$$

The values of magnetic field necessary to produce this

absorption of molecular beam are of the same order of the fields that exist around the sun spots. The sun's field is about 50 gauss while the spots have fields varying from 100 to 4,000 gauss (23). For small fields in the neighborhood of 100 gauss absorption of Na^{23} has taken place at 4 meters. For fields of 660 gauss frequencies of 1.36 meter radiation was absorbed.

A mechanism of this sort would account very reasonably for the enhanced solar radiation associated with sun spots and flares. However, the discreet frequencies emitted are not registered as single frequencies on any recording equipment. Before the subject of this changeover from discreet line or band spectra to blackbody radiation of gases is approached another set of experiments might be reviewed. Steinberg (25) was interested in cold cathode and hot cathode discharge phenomena. When discharges from these bodies were placed in a transverse magnetic field they were found to yield high values of noise voltages. The work utilized high frequency receivers in the 200 megacycle range. Noise occurred only when the magnetic field was applied near the anode of the tube. When the magnetic field was removed the noise decreased rapidly. Noise level appeared as a function of magnetic field, reaching a sharp maximum for some fixed value of the field.

Magnetic fields producing single lines or bands fail to give an experimentally verifiable picture of the equivalent

blackbody radiation of solar noise bursts. Although blackbody emission can be approached by gases to a much lesser extent than by cavity radiators, it can be approximated by increasing the thickness of the radiating layer of the gas, if the absorption coefficient is different from zero for every wave length in the spectral region under consideration. If the temperature and pressure are high, the required radiating layer is thinner for approaching blackbody radiation (8).

NEW APPROACHES TO SOLAR NOISE

Measurements of extremely low audio frequency radiation has been made by two different groups. Values in the order of 1800 u volts per meter for a frequency of 5 cycles per second were recorded by means of a coil wound on a long laminated mu metal core (26). An isolated site was used with a wave analyzer of 4 cycle bandwidth acting as receiver. Above 100 cycles per second the receiver showed no increase in noise above ordinary receiver noise power (see Figure 6). There was no directivity in the horizontal plane but the vertical plane showed a smaller component of intensity than the horizontal.

Menzel and Salisbury made the measurements in the same frequency regions and received amplitudes even greater than the above results. They offer the explanation that the low frequencies arise from mechanical turbulence in the highly ionized atmosphere of the sun. Since cosmic rays consist of ionized particles, it is possible to show that an electron

with an energy of over 10^6 volts shows a rapidly increasing effective mass when changes due to relativity are brought into the equation for refractive index. Therefore, the critical frequency for waves associated with these particles is reduced and low frequency waves penetrate the ionosphere(15)

u (the refractive index) $= \sqrt{1 - \frac{e^2}{4\pi^2 m} 10^{-6}}$

Another factor which must be taken into account for the understanding of the ionosphere is the result of this low frequency series of experiments and of the routine propagational studies. There is evidently a band of frequencies that is eliminated as far as reception on the earth is concerned. The Willis experiments showed that beyond 1000 cycles per second no noise was received above receiver noise. Between 4 megacycles and 1000 cycles the ionosphere acts like a band rejection network. It will be interesting to see work done on the shifting of the upper and lower limits of this filter as a function of sunspots, cosmic rays, etc.

Much work must be done in this field before the necessary correlations are proven. Experimental work is now taking place to uncover relations between amplitude of these audio signals with seismographic information, with sunspots, and with overall weather changes.

CONCLUSION

There is a need for a comprehensive program to study simultaneously the various effects of sunspots and associated

solar phenomena. The time correlation of cosmic rays, audio frequency noise, solar and cosmic radio frequency noise, magnetic disturbances on the earth and D layer ionization should be undertaken at the same place. Such plans are maturing in the Sacramento Peak Upper Air Station in New Mexico where the Air Forces, Harvard University and Cornell University are collaborating on equipment and personnel for integrating such measurements.

Since solar noise bursts enhance D layer ionization thus to some extent attenuating the same radiation that is being generated, it will be possible to differentiate between various levels of upper atmosphere ionization by measuring the attenuation of a source of steady energy such as Sagittarius. The ratio of noise power received during a "quiet sun" period to noise power received during a burst would give a positive indication of ionization density and attenuation.

A definite theory of solar noise bursts would aid greatly in explaining the origin of cosmic rays. Since these phenomena tie together, work carried on in the field might produce a single theory capable of taking into account the various bits of isolated experimental evidence.

ABSTRACT

New techniques in electronic design and in antenna design have aided in forming a new field -- that of radio astronomy. Investigations of radiation from the sun have been broadened to include the radio frequency and microwave bands.

Interest in research stems from radio propagational needs and from astronomical problems. Navigational techniques might utilize solar and cosmic noise as celestial all-weather points. Much interest stems from an integrating movement in physics, that which would tie up electromagnetic radiation and nuclear theory.

Cosmic noise, a more intense source than ordinary "quiet sun" solar noise, was first detected in 1932. More sensitive equipment aided in the discovery of solar noise.

Since the two sources of energy (the sun and the cosmos) are of low intensity highly directive antennas are needed along with sensitive low noise receivers. Measurements are made of the steradiancy of the radiant flux per unit solid angle per square centimeter. For the sun the energy is converted into an equivalent blackbody which would radiate that amount of energy. From optical measurements the sun has been conceived as a generator of 6800 degrees K.

Receiver noise or thermal noise is frequency independent but dependent on bandwidth. The equivalence of thermal noise to blackbody radiation is due to the fact that Planck's Law

reduces to Rayleigh Jean's Law involving the fourth power of frequency at radio frequencies. In converting units and going from volume to area this will involve the second power of frequency. This may be compared to the power a directive radio frequency antenna will absorb which is proportional to the second power of wavelength. Therefore, the result will be frequency independent. Thermal noise is then used as a signal generator and the results tabulated in blackbody temperatures.

The noise figure is shown to be equal to:

actual noise output power of a network/noise power of same network in an ideal state.

High antenna gains are needed to override 6800° K solar noise. However, the "quiet sun" measurements seem to be in the order of 1,000,000° blackbody temperature. Only the microwave region shows signs of being below this measurement. The corona's temperature of approximately this value might be the answer.

Sunspot activity enhances radiation many times, occasionally as high as 10^6 normal "quiet sun" noise. In two cases high cosmic ray intensities were shown to come at about the same times as enhanced solar noise and visible flares. Higher frequency bursts arrive first. Solar flares become visible at about the same time as cosmic ray intensities increase. Radio fadeouts are followed finally by magnetic storms. Enhanced solar radiation shows circular polarization.

Cosmic noise comes from two main sources. There is a large steady source at Sagittarius and a variable source at

Cygnus. Measurements corroborate one another at various frequencies.

The change in energy levels due to placing strong steady magnetic fields yields a reasonable solution to the problem of the origin of enhanced solar noise. Molecular beam resonance experiments show absorption of radio frequency energy. Hot and cold cathode techniques yield large values of noise when a magnetic field is placed near the anode. Blackbody radiation can be approached by gases by increasing the thickness of the radiating layer of the gas.

Low audio frequency measurements have been taken. Unusually high values of intensity were found. It seems likely that these measurements are tied into studies of cosmic rays. All this work must be studied so as to be able to coordinate the information into a unified theory which would explain low frequency audio measurements, solar and cosmic noise, and cosmic ray intensities.

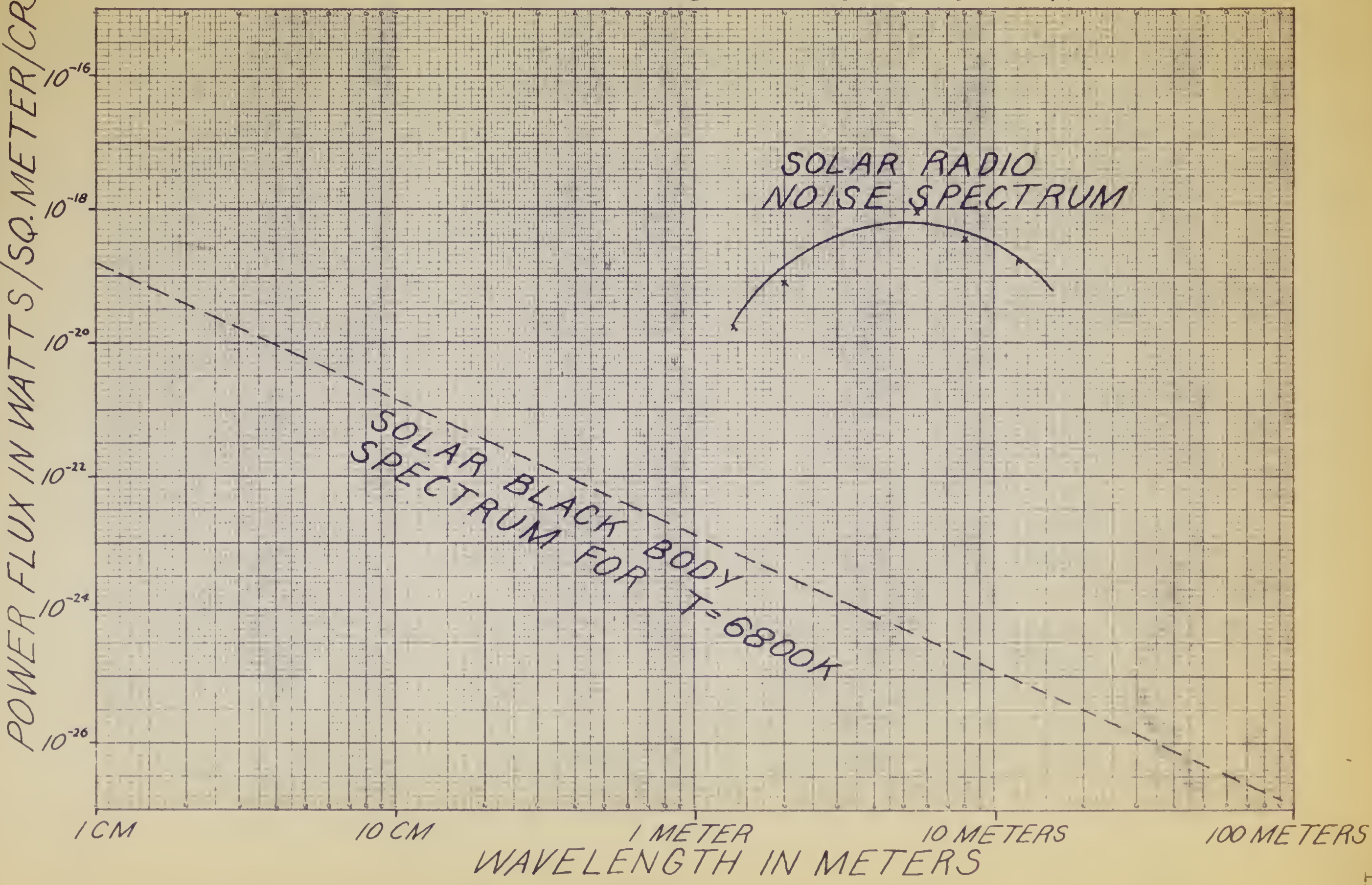
QUIET SUN MEASUREMENTS

Frequency	Apparent Temperature	Remarks	Publication Data
160 mc	300 x blackbody		Reber Ap J 100 279 1944
200 mc	50 x blackbody		Pawsey, Payne-Scott, McCready, Nature 157 47, 1946
400 mc	200 x blackbody		Observer, Feb 1947 Reber
3000 mc			Southworth
10,000 mc	Blackbody (6800)		J. Franklin Inst. 239, 285, 1945
25,000 mc			
24,000 mc	10,000 degrees plus or minus 1,000 K	Radiometer calibration with the sun assumed to be a uniformly illuminated disk.	Dicke and Beringer Apl J 103, 375, 1946

FIGURE 1.

NO 31.226 20 DIVISIONS PER INCH (120 DIVISIONS) BY FOUR CYCLE RATIO RULING. CODEX BOOK COMPANY INC NORWOOD

FIGURE 2: COMPARISON OF THEORETICAL BLACK BODY SPECTRUM AND SOLAR RADIO NOISE SPECTRUM.



SOLAR NOISE BURST MEASUREMENTS

Frequency	Apparent Temperature Peaks	Remarks	Publication Data
44.9 mc	---	Fluctuation noise had the character of hissing.	Norton and Allen - U.S. Fed. Comm. Rep., Feb. 1946
25 to 200 mc	10^6 BB	Max enhancement at 64 mc,greatest solar noise did not occur when large sunspots centrally located on disk.	Appleton and Hey: Phil. Mag. 37, 73, 1946
60 mc	10^5 BB	Presence of sunspot group first noted in conjunction with enhanced solar noise.	Nature 156, 534, 1945 Measurements, Feb.26-28, 1942.
75 mc	10^8 BB	Short period variability: changes by factor of 100 with a few seconds.	Williams and Hand: Nature 158, 511,1946
85 mc		Circular polization noted.	Appleton and Hey: Nature, 158, 339,1946
175		High resolution antennas. Enhanced solar radiation originates in an area smaller than solar disk.	Ryle and Vonberg: Nature, 158, 339, 1946.
200 mc	$2x10^3$ BB	Minimum of 50 x BB noted.	Pawsey, Payne-Scott: McCready: Nature, 157, 47, 1946
200 mc		Enhanced solar radiation showed circular polarization	Nature 158, 308, 1946, Martyn.

FIGURE 3

SOLAR NOISE BURST MEASUREMENTS (CONTD)

Frequency	Apparent Temperature Peaks	Remarks	Publication Data
480 mc	10^5 BB		Reber: Nature 158, 945, 1946
1200 mc	BB	Taken at same time as 200 mc measurements showed $2x10^3$ over BB.	Paysey Payne-Scott, McCready: Nature, 157, 47, 1946.
3000 mc	x	Blackbody temperature of solar disk calculated to be 7.8×10^4 K.	IRE, April, 1948, Covington

FIGURE 3.

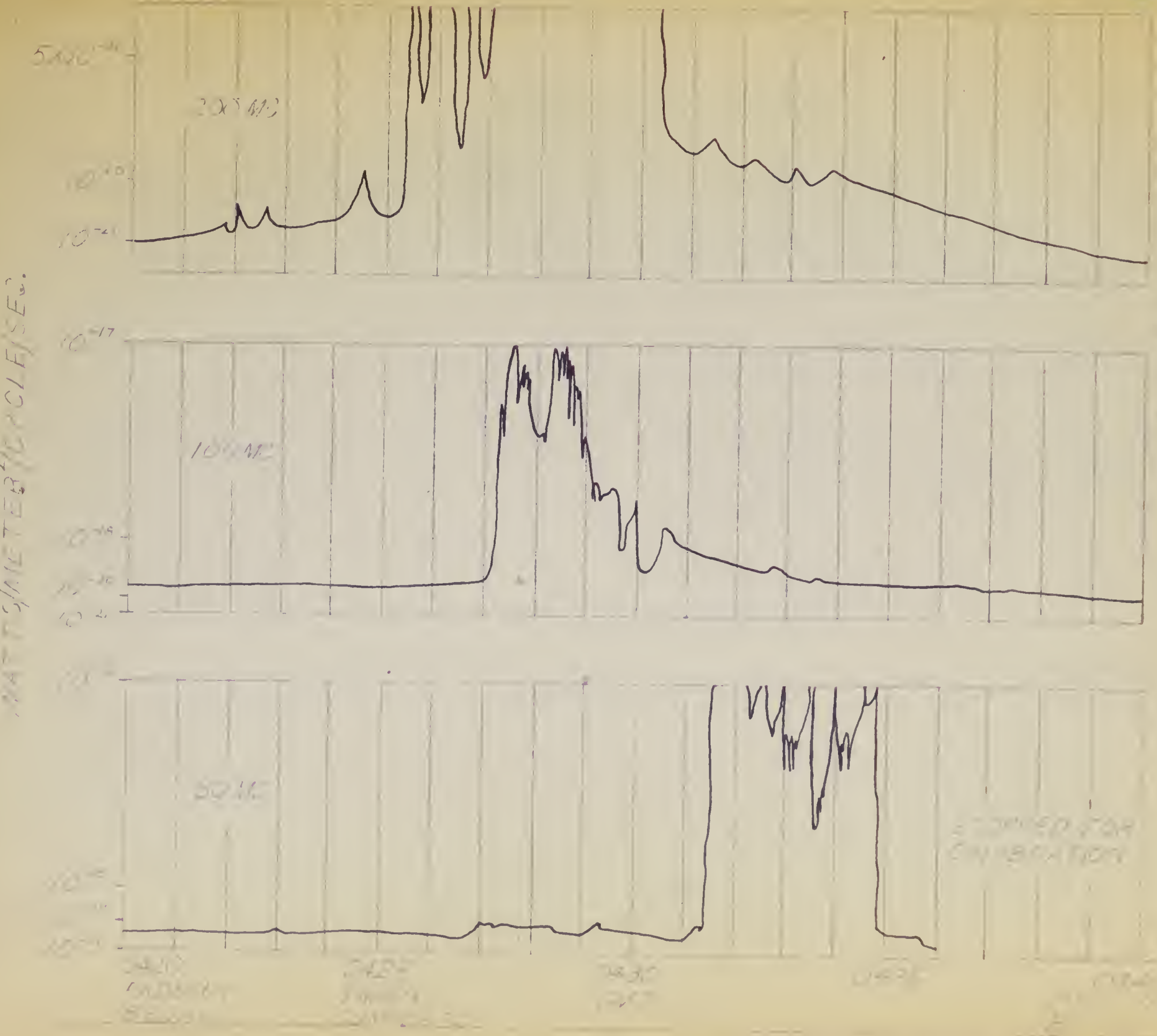


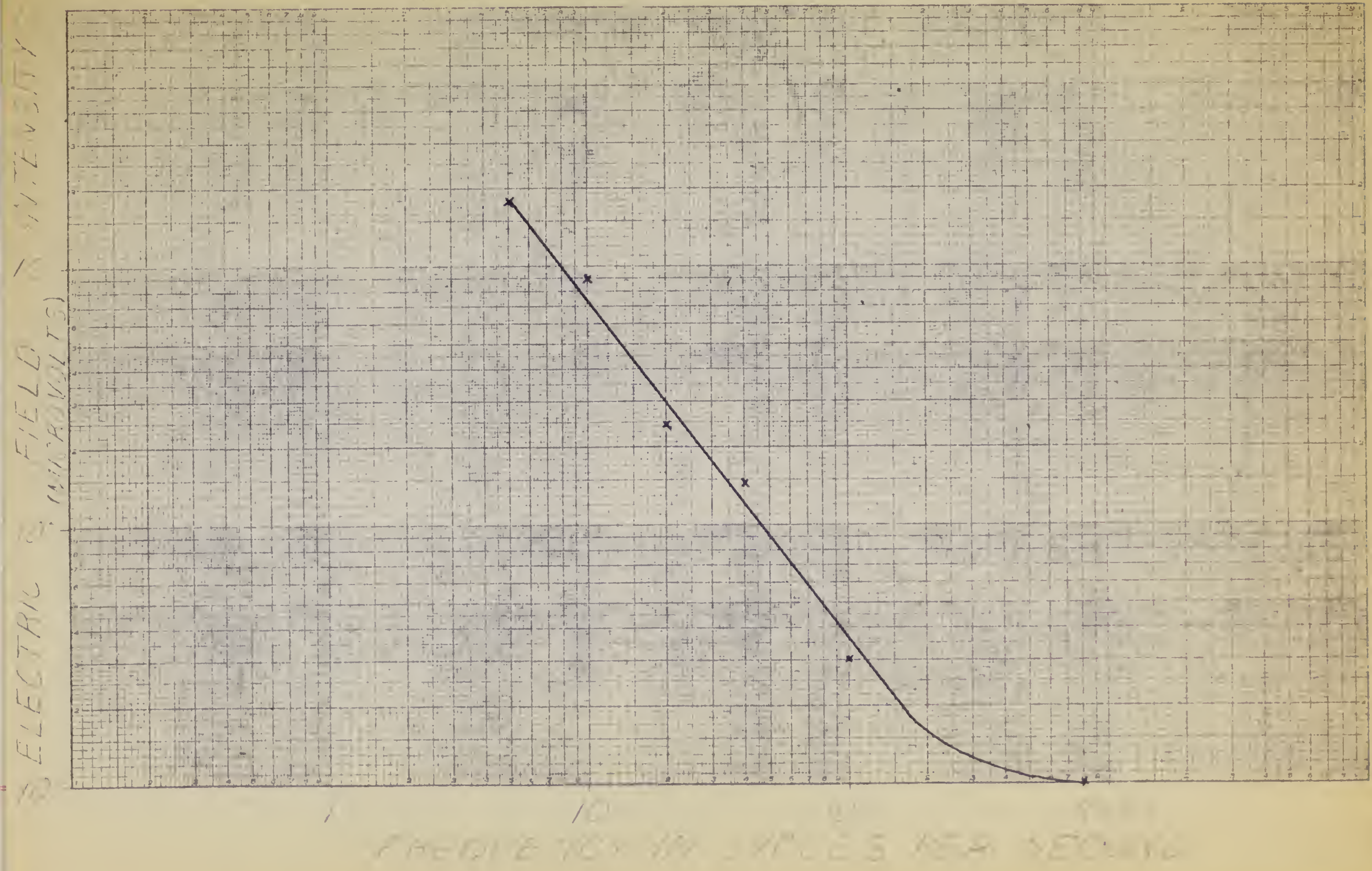
FIGURE 4: TIME SEQUENCE OF A SOLAR NOISE.

COSMIC NOISE MEASUREMENTS

Frequency	Absolute Intensity (in watts/cm^2/circ deg/mc of bandwidth for main source of radiation.	Remarks	Publication Data
20.6 mc	14 x 10^{-22}	First measurement of cosmic or solar noise.	K. Janksy: Proc. IRE, 21 1387, 1933, Proc IRE 20 1920, 1932
30 mc		Widths of source in Sagittarius fixed at 11°.	Franz: Hockfrequenztechnik, 59 143 1942
64 mc	3.2 x 10^{-22}	Minor disturbance in Cygnus produced a signal which was a rapidly fluctuating function of time.	Hey, Phillips Parsons: Nature, 158,234, 1944
160 mc	11 x 10^{-22}	Center of maximum disturbance fixed to be near galactic nucleus in Sagittarius.	Reber: Ap J 91, 621, 1940
480 mc	6 x 10^{-22}		Greenstein and Reber: Observatory, Feb 1947.

FIGURE 5.

FIGURE E-A. THE FREQUENCY
[illegible] IN MEASUREMENTS



BIBLIOGRAPHY

1. Appleton and Hey: Solar Radio Noise; Philosophical Magazine, London: Feb. 1946.

2. Bolton and Stanley: Observations on the Variable Source of Cosmic Radio Frequency Radiation in the Constellation of Cygnus: Australian Journal of Sci. Res.: March 1948.

3. Burrows: Radio Astronomy Electronics: February 1949.

4. Covington: Solar Noise on 10 Cm: Proc. IRE: April 1948.

5. Covington: Circularly Polarized Solar Radiation on 10.7 Cm: Proc. IRE: April 1949.

6. Dicke: The Measurement of Thermal Radiation at Microwave Frequencies: Review of Scientific Instruments: Vol. 17, p 268, July 1946.

7. Dolbear and Elliot: Cosmic Ray Intensity at Manchester and Solar Disturbances of July 25, 1946.

8. Finkelnburg: Conditions for Blackbody Radiation of Gases: J. Opt Soc: February 1949.

9. Forbush, Fill, Vallarta: On the Mechanism of Sudden Increases of Cosmic Radiation Associated with Solar Flares: Rev. Mod. Phy.: January 1949.

10. Forsythe: W.E. ed.: Measurement of Radiant Energy: McGraw-Hill: 1937.

11. Goldman, S.: Frequency Analysis Modulation and Noise: McGraw-Hill: 1948.

12. Greenstein and Reber: RF Investigations of Astronomical Interest: Observatory, London: February 1947.

13. Jansky, K: Direction Studies of Atmospherics at High Frequencies: Proc IRE: December 1932.

14. Martyn: Polarization of Solar Radio Frequency Emissions: Nature, London: Vol 158, p 308: 1946.

15. Menzel and Salisbury: Origin of Cosmic Rays: Nucleonics: April 1948.

16. Payne-Scott: Relative Times of Arrival of Bursts of Noise on Different Radio Frequencies: Nature, London, Vol 160 p 256, 1947.

17. Radio Frequency Spectra of Atoms: Physical Review: 1 May 1940.

18. Reber, G: Cosmic Static: Astrophysical Journal: November 1944.

19. Richtmyer and Kennard: *Introduction to Modern Physics*: McGraw-Hill Co., Fourth Edition: 1947.

20. Russell-Dugan-Steward: *Astronomy Vol I: The Solar System*: Ginn and Co., New York, N. Y., Revised Edition: 1945.

21. Ryle and Vonberg: *Investigation of RF Radiation from the Sun*: Proc. Royal Soc. A., London: 22 April 1948.

22. Ryle and Vonberg: Solar Radiation at 175 mc: Nature, London: Vol 158, p 339: 1946.

23. Saha: Conditions of Escape of RF Energy from the Sun and Stars: Nature, London: Vol. 158, p 549: 1946.

24. Shklovsky, J: Emission of Radio Waves by Galaxy and Sun: Nature, London: Vol. 159: 1947.

25. Steinberg: The Production of High Frequency Energy in Ionized Gases in a Magnetic Field: Nature, London: Vol. 160, p 833: 1947.

26. Willis, H: Audio Frequency Magnetic Fluctuations: Nature, London: Vol. 161; June 5, 1948.

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